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US 6012521 A US 5749585 A
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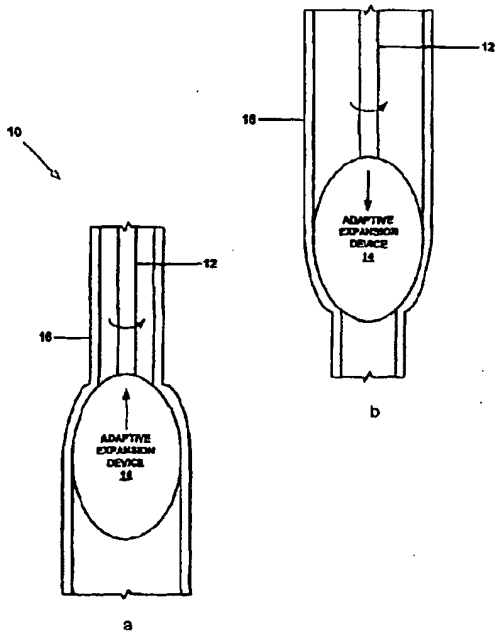
(54) Abstract Title: **Apparatus and method for radially expanding a wellbore casing using an adaptive expansion system**

(57) An apparatus and method for radially expanding a wellbore (34) using an adaptive expansion device (14).



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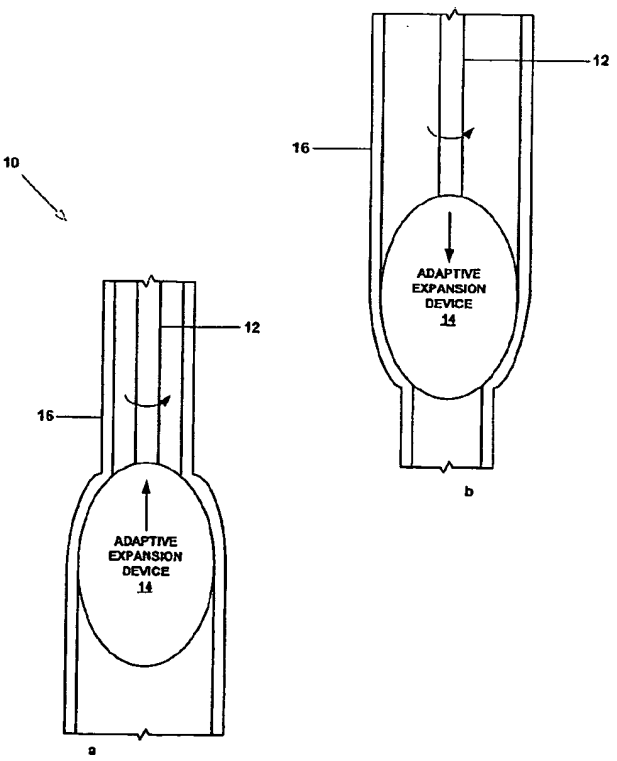
(54) Title: APPARATUS AND METHOD FOR RADIALLY EXPANDING A WELLBORE CASING USING AN ADAPTIVE EXPANSION SYSTEM

(57) Abstract: An apparatus and method for radially expanding a wellbore using an adaptive expansion system.



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APPARATUS AND METHOD FOR RADIALLY EXPANDING A WELLBORE CASING USING AN ADAPTIVE EXPANSION SYSTEM

Cross Reference To Related Applications

[001] The present application claims the benefit of the filing date of U.S. provisional patent application serial no. 60/455,124, attorney docket no. 25791.241, filed on March 17, 2003, the disclosure of which is incorporated herein by reference.

[002] The present application is related to the following: (1) U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, which claims priority from provisional application 60/121,702, filed on 2/25/99, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (4) U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (5) U.S. patent application serial no. 10/169,434, attorney docket no. 25791.10.04, filed on 7/1/02, which claims priority from provisional application 60/183,546, filed on 2/18/00, (6) U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (7) U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (8) U.S. patent number 6,575,240, which was filed as patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, which claims priority from provisional application 60/121,907, filed on 2/26/99, (9) U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (10) U.S. patent application serial no. 09/981,916, attorney docket no. 25791.18, filed on 10/18/01 as a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (11) U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (12) U.S. patent application serial no. 10/030,593, attorney docket no. 25791.25.08, filed on 1/8/02, which claims priority from provisional application 60/146,203, filed on 7/29/99, (13) U.S. provisional patent application serial no. 60/143,039, attorney docket no. 25791.26, filed

on 7/9/99, (14) U.S. patent application serial no. 10/111,982, attorney docket no. 25791.27.08, filed on 4/30/02, which claims priority from provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (15) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (16) U.S. provisional patent application serial no. 60/438,828, attorney docket no. 25791.31, filed on 1/9/03, (17) U.S. patent number 6,564,875, which was filed as application serial no. 09/679,907, attorney docket no. 25791.34.02, on 10/5/00, which claims priority from provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (18) U.S. patent application serial no. 10/089,419, filed on 3/27/02, attorney docket no. 25791.36.03, which claims priority from provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (19) U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (20) U.S. patent application serial no. 10/303,992, filed on 11/22/02, attorney docket no. 25791.38.07, which claims priority from provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (21) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (22) U.S. provisional patent application serial no. 60/455,051, attorney docket no. 25791.40, filed on 3/14/03, (23) PCT application US02/2477, filed on 6/26/02, attorney docket no. 25791.44.02, which claims priority from U.S. provisional patent application serial no. 60/303,711, attorney docket no. 25791.44, filed on 7/6/01, (24) U.S. patent application serial no. 10/311,412, filed on 12/12/02, attorney docket no. 25791.45.07, which claims priority from provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (25) U.S. patent application serial no. 10/, filed on 12/18/02, attorney docket no. 25791.46.07, which claims priority from provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (26) U.S. patent application serial no. 10/322,947, filed on 1/22/03, attorney docket no. 25791.47.03, which claims priority from provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (27) U.S. patent application serial no. 10/406,648, filed on 3/31/03, attorney docket no. 25791.48.06, which claims priority from provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (28) PCT application US02/04353, filed on 2/14/02, attorney docket no. 25791.50.02, which claims priority from U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (29) U.S. patent application serial no. 10/465,835, filed on 6/13/03, attorney docket no. 25791.51.06, which claims priority from provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (30) U.S. patent application serial no. 10/465,831, filed on 6/13/03, attorney docket no. 25791.52.06,

which claims priority from U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (31) U.S. provisional patent application serial no. 60/452,303, filed on 3/5/03, attorney docket no. 25791.53, (32) U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (33) U.S. patent number 6,561,227, which was filed as patent application serial number 09/852,026 , filed on 5/9/01, attorney docket no. 25791.56, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (34) U.S. patent application serial number 09/852,027, filed on 5/9/01, attorney docket no. 25791.57, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (35) PCT Application US02/25608, attorney docket no. 25791.58.02, filed on 8/13/02, which claims priority from provisional application 60/318,021, filed on 9/7/01, attorney docket no. 25791.58, (36) PCT Application US02/24399, attorney docket no. 25791.59.02, filed on 8/1/02, which claims priority from U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (37) PCT Application US02/29856, attorney docket no. 25791.60.02, filed on 9/19/02, which claims priority from U.S. provisional patent application serial no. 60/326,886, attorney docket no. 25791.60, filed on 10/3/2001, (38) PCT Application US02/20256, attorney docket no. 25791.61.02, filed on 6/26/02, which claims priority from U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (39) U.S. patent application serial no. 09/962,469, filed on 9/25/01, attorney docket no. 25791.62, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (40) U.S. patent application serial no. 09/962,470, filed on 9/25/01, attorney docket no. 25791.63, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (41) U.S. patent application serial no. 09/962,471, filed on 9/25/01, attorney docket no. 25791.64, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (42) U.S. patent application serial no. 09/962,467, filed on 9/25/01, attorney docket no. 25791.65, which is a divisional of U.S. patent application serial

no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (43) U.S. patent application serial no. 09/962,468, filed on 9/25/01, attorney docket no. 25791.66, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (44) PCT application US 02/25727, filed on 8/14/02, attorney docket no. 25791.67.03, which claims priority from U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, and U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (45) PCT application US 02/39425, filed on 12/10/02, attorney docket no. 25791.68.02, which claims priority from U.S. provisional patent application serial no. 60/343,674 , attorney docket no. 25791.68, filed on 12/27/2001, (46) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (47) U.S. utility patent application serial no. 10/516,467, attorney docket no. 25791.70, filed on 12/10/01, which is a continuation application of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (48) PCT application US 03/00609, filed on 1/9/03, attorney docket no. 25791.71.02, which claims priority from U.S. provisional patent application serial no. 60/357,372 , attorney docket no. 25791.71, filed on 2/15/02, (49) U.S. patent application serial no. 10/074,703, attorney docket no. 25791.74, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (50) U.S. patent application serial no. 10/074,244, attorney docket no. 25791.75, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (51) U.S. patent application serial no. 10/076,660, attorney docket no. 25791.76, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (52) U.S. patent application serial no. 10/076,661, attorney docket no. 25791.77, filed on 2/15/02, which is a divisional of U.S. patent number

6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (53) U.S. patent application serial no. 10/076,659, attorney docket no. 25791.78, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (54) U.S. patent application serial no. 10/078,928, attorney docket no. 25791.79, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (55) U.S. patent application serial no. 10/078,922, attorney docket no. 25791.80, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (56) U.S. patent application serial no. 10/078,921, attorney docket no. 25791.81, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (57) U.S. patent application serial no. 10/261,928, attorney docket no. 25791.82, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (58) U.S. patent application serial no. 10/079,276 , attorney docket no. 25791.83, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (59) U.S. patent application serial no. 10/262,009, attorney docket no. 25791.84, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (60) U.S. patent application serial no. 10/092,481, attorney docket no. 25791.85, filed on 3/7/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (61) U.S. patent application serial no. 10/261,926, attorney docket no. 25791.86, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional

application 60/137,998, filed on 6/7/99, (62) PCT application US 02/36157, filed on 11/12/02, attorney docket no. 25791.87.02, which claims priority from U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/01, (63) PCT application US 02/36267, filed on 11/12/02, attorney docket no. 25791.88.02, which claims priority from U.S. provisional patent application serial no. 60/339,013, attorney docket no. 25791.88, filed on 11/12/01, (64) PCT application US 03/11765, filed on 4/16/03, attorney docket no. 25791.89.02, which claims priority from U.S. provisional patent application serial no. 60/383,917, attorney docket no. 25791.89, filed on 5/29/02, (65) PCT application US 03/15020, filed on 5/12/03, attorney docket no. 25791.90.02, which claims priority from U.S. provisional patent application serial no. 60/391,703, attorney docket no. 25791.90, filed on 6/26/02, (66) PCT application US 02/39418, filed on 12/10/02, attorney docket no. 25791.92.02, which claims priority from U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/02, (67) PCT application US 03/06544, filed on 3/4/03, attorney docket no. 25791.93.02, which claims priority from U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/02, (68) U.S. patent application serial no. 10/331,718, attorney docket no. 25791.94, filed on 12/30/02, which is a divisional U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (69) PCT application US 03/04837, filed on 2/29/03, attorney docket no. 25791.95.02, which claims priority from U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/02, (70) U.S. patent application serial no. 10/261,927, attorney docket no. 25791.97, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (71) U.S. patent application serial no. 10/262,008, attorney docket no. 25791.98, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (72) U.S. patent application serial no. 10/261,925, attorney docket no. 25791.99, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (73) U.S. patent application serial no. 10/199,524, attorney docket no. 25791.100, filed on 7/19/02, which is a continuation of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (74) PCT application US

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Background of the Invention

[003] This invention relates generally to oil and gas exploration, and in particular to forming and repairing wellbore casings to facilitate oil and gas exploration.

[004] Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due

to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings. Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

[005] The present invention is directed to overcoming one or more of the limitations of the existing procedures for forming and/or repairing wellbore casings.

Summary of the Invention

[006] According to one aspect of the present invention, an apparatus for radially expanding and plastically deforming a tubular member is provided that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member that includes a support structure coupled to the support member; one or more expansion device segments for engaging the tubular member to thereby radially expand and plastically deform the tubular member; one or more adjustable spring elements coupled between the support structure and one or more of the expansion device segments; one or more adjustable damping elements coupled between the support structure and one or more of the expansion device segments; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member by the adaptive expansion device; a controller operably coupled to the adjustable spring elements, the adjustable damping elements, and the sensors; and a user interface operably coupled to the controller for receiving user inputs; wherein the controller is programmed to controllably adjust a spring rate of one or more of the adjustable spring elements, and a damping rate of one or more of the damping elements as a function of the operating conditions sensed by the sensors and the user inputs.

[007] According to another aspect of the present invention, a method of adaptively radially expanding a tubular member within a wellbore is provided that includes inserting an adaptive expansion device into the tubular member; radially expanding and plastically deforming the tubular member using the adaptive expansion device; sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and as a function of the sensed operating conditions, controllably adjusting a spring rate and a damping rate of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[008] According to another aspect of the present invention, a system for adaptively radially expanding a tubular member within a wellbore is provided that includes means for inserting an adaptive expansion device into the tubular member; means for radially expanding and plastically deforming the tubular member using the adaptive expansion device; means for sensing one or more operating conditions during the radial expansion and plastic

deformation of the tubular member; and means for, as a function of the sensed operating conditions, controllably adjusting a spring rate and a damping rate of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[009] According to another aspect of the present invention, an apparatus for radially expanding and plastically deforming a tubular member is provided that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member that includes a support structure coupled to the support member; one or more expansion device segments for engaging the tubular member to thereby radially expand and plastically deform the tubular member; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member by the adaptive expansion device; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust a frequency characteristic of one or more of the expansion device segments as a function of the operating conditions sensed by the sensors.

[0010] According to another aspect of the present invention, a method of adaptively radially expanding a tubular member within a wellbore is provided that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the tubular member; radially expanding and plastically deforming the tubular member using the adaptive expansion device; sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and as a function of the sensed operating conditions, controllably adjusting a frequency response characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member.

[0011] According to another aspect of the present invention, a system for adaptively radially expanding a tubular member within a wellbore is provided that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the tubular member; means for radially expanding and plastically deforming the tubular member using the adaptive expansion device; means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and means for, as a function of the sensed operating conditions, controllably adjusting a frequency response characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member.

[0012] According to another aspect of the present invention, an apparatus for radially expanding and plastically deforming overlapping ends of first and second tubular members is provided that includes a support member; and an adaptive expansion device coupled to the

support member for radially expanding and plastically deforming the overlapping ends of the tubular members that includes a support structure coupled to the support member; one or more expansion device segments for engaging the overlapping ends of the tubular members to thereby radially expand and plastically deform the overlapping ends of the tubular member; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the overlapping ends of the tubular member by the adaptive expansion device; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the overlapping ends of the tubular members by one or more of the sensors.

[0013] According to another aspect of the present invention, a method of adaptively radially expanding overlapping ends of tubular members within a wellbore is provided that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the overlapping ends of the tubular members; radially expanding and plastically deforming the overlapping ends of the tubular members using the adaptive expansion device; sensing the overlapping ends of the tubular members during the radial expansion and plastic deformation of the overlapping ends of the tubular members; and as a function of the sensing of the overlapping ends of the tubular members, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the overlapping ends of the tubular members.

[0014] According to another aspect of the present invention, a system for adaptively radially expanding overlapping ends of tubular members within a wellbore is provided that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the overlapping ends of the tubular members; means for radially expanding and plastically deforming the overlapping ends of the tubular members using the adaptive expansion device; means for sensing the overlapping ends of the tubular members during the radial expansion and plastic deformation of the overlapping ends of the tubular members; and means for, as a function of the sensing of the overlapping ends of the tubular members, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the overlapping ends of the tubular members.

[0015] According to another aspect of the present invention, an apparatus for radially expanding and plastically deforming first and second tubular members coupled to one another by a threaded connection is provided that includes a support member; and an

adaptive expansion device coupled to the support member for radially expanding and plastically deforming the threaded connection that includes a support structure coupled to the support member; one or more expansion device segments for engaging the threaded connection to thereby radially expand and plastically deform the threaded connection; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the threaded connection by the adaptive expansion device; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the threaded connection by one or more of the sensors.

[0016] According to another aspect of the present invention, a method of adaptively radially expanding tubular members coupled to one another by a threaded connection within a wellbore is provided that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular members proximate the threaded connection; radially expanding and plastically deforming the threaded connection using the adaptive expansion device; sensing the threaded connection during the radial expansion and plastic deformation of the threaded connection; and as a function of the sensing of the threaded connection, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the threaded connection.

[0017] According to another aspect of the present invention, a system for adaptively radially expanding tubular members coupled to one another by a threaded connection within a wellbore is provided that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular members proximate the threaded connection; means for radially expanding and plastically deforming the threaded connection using the adaptive expansion device; means for sensing the threaded connection during the radial expansion and plastic deformation of the threaded connection; and means for, as a function of the sensing of the threaded connection, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the threaded connection.

[0018] According to another aspect of the present invention, an apparatus for radially expanding and plastically deforming a tubular member within a wellbore that traverses a subterranean formation is provided that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation that includes a support structure coupled to the support member; one or more expansion device

segments for engaging the threaded connection to thereby radially expand and plastically deform the tubular member and elastically deform the subterranean formation; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the subterranean formation by one or more of the sensors.

[0019] According to another aspect of the present invention, a method of adaptively radially expanding a tubular member within a wellbore that traverses a subterranean formation is provided that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation within the wellbore; radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation using the adaptive expansion device; sensing the subterranean formation during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and as a function of the sensing of the subterranean formation, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation.

[0020] According to another aspect of the present invention, a system for adaptively radially expanding a tubular member within a wellbore that traverses a subterranean formation is provided that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation within the wellbore; means for radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation using the adaptive expansion device; means for sensing the subterranean formation during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and means for, as a function of the sensing of the subterranean formation, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation.

[0021] According to another aspect of the present invention, an apparatus for radially expanding and plastically deforming a tubular member is provided that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member that includes a support structure

coupled to the support member; and one or more expansion device segments coupled to the support structure for engaging the tubular member to thereby radially expand and plastically deform the tubular member; one or more sensors for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and a controller operably coupled to the expansion device segments and the sensors; and wherein the controller is programmed to controllably adjust one or more of the operational characteristics of one or more the expansion device segments as a function of the operating conditions sensed by the sensors.

[0022] According to another aspect of the present invention, a method of adaptively radially expanding a tubular member within a wellbore is provided that includes inserting an adaptive expansion device into the tubular member; radially expanding and plastically deforming the tubular member using the adaptive expansion device; sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and as a function of the sensed operating conditions, controllably adjusting one or more of the operating characteristics of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[0023] According to another aspect of the present invention, a system for adaptively radially expanding a tubular member within a wellbore is provided that includes means for inserting an adaptive expansion device into the tubular member; means for radially expanding and plastically deforming the tubular member using the adaptive expansion device; means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and means for, as a function of the sensed operating conditions, controllably adjusting one or more of the operating characteristics of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

Brief Description of the Drawings

[0024] Figs. 1a and 1b are fragmentary cross sectional illustrations of an exemplary embodiment of an adaptive system for radially expanding a tubular member.

[0025] Fig. 2 is a schematic illustration of an exemplary embodiment of the adaptive expansion device of the system of Figs. 1a and 1b.

[0026] Figs. 3a-3c are fragmentary cross sectional illustrations of exemplary embodiments of the operation of the adaptive system of Figs. 1a and 1b.

Detailed Description of the Illustrative Embodiments

[0027] Referring to Figs. 1a, 1b, and 2, an adaptive system 10 for radially expanding a tubular member includes a support member 12 and an adaptive expansion device 14. In several exemplary embodiments, the system 10 may be used to radially expand and plastically deform a tubular member 16 by displacing the expansion device 14 in the longitudinal direction and/or by rotating the expansion device relative to the tubular member.

[0028] In an exemplary embodiment, the adaptive expansion device 14 includes one or more expansion device segments 18 for engaging, and thereby radially expanding and plastically deforming the tubular member 16, that are coupled to an expansion device support structure 20 by one or more conventional adjustable spring elements 22 and one or more conventional adjustable damping elements 24. In several exemplary embodiments, the adjustable spring elements 22 and/or the adjustable damping elements 24 are be provided as disclosed in one or more of the following: 1) U.S. Patent No. 6,431,284, 2) U.S. Patent No. 6,390,956, 3) U.S. Patent No. 6,296,533, 4) U.S. Patent No. 6,237,889, 5) U.S. Patent No. 6,220,089, 6) U.S. Patent No. 6,159,289, 7) U.S. Patent No. 6,105,988, 8) U.S. Patent No. 6,065,741, 9) U.S. Patent No. 6,062,324, 10) U.S. Patent No. 6,035,954, 11) U.S. Patent No. 5,947,458, 12) U.S. Patent No. 5,875,567, 13) U.S. Patent No. 5,713,088, 14) U.S. Patent No. 5,603,574, 15) U.S. Patent No. 5,364,565, 16) 5,531,522, 17) U.S. Patent No. 5,464,197, 18) U.S. Patent No. 5,421,655, 19) U.S. Patent No. 5,201,392, 20) U.S. Patent No. 5,169,129, 21) U.S. Patent No. 5,005,820, 22) U.S. Patent No. 4,984,632, 23) U.S. Patent No. 4,862,995, 24) U.S. Patent No. 4,789,343, 25) U.S. Patent No. 4,657,280, 26) U.S. Patent No. 4,624,477, 27) U.S. Patent No. 4,575,058, 28) U.S. Patent No. 4,566,717, 29) U.S. Patent No. 4,509,403, 30) U.S. Patent No. 4,277,045, and/or 31) U.S. Patent No. 4,071,104, the disclosures of which are incorporated herein by reference.

[0029] In several exemplary embodiments, the expansion device segments 18 include, for example, segments of a conventional expansion cone and/or conventional roller expansion elements and/or conventional hydro-forming elements. The expansion device support structure 20 is also coupled to the support member 12. The adjustable spring and damping elements, 22 and 24, are also operably coupled to a controller 26, and one or more sensors 28 are also operably coupled to the controller 26 for reasons to be described. A user interface 28 may also be provided that is operably coupled to the controller 26. In several exemplary embodiments, the controller 26 includes analog, digital, electronic, and/or hydraulic control elements that may or may not be positioned within the adaptive expansion device 14. In several alternative embodiments, the user interface 28 may include a conventional keyboard input device and/or a conventional display device and/or a conventional communication channel for linking the user interface to the controller 26.

[0030] In an exemplary embodiment, during the operation of the system 10, the controller 26 is programmed to adjust the spring rate of the adjustable spring elements 22 and/or the damping rate of the adjustable damping elements 24 as a function of one or more operating conditions that are sensed by the sensors 28. In several exemplary embodiments, the sensed operating conditions may include the reaction forces of the tubular member 16, the operating pressure of fluidic materials within the system 10 and/or the tubular member, the

rotational speed of the system, the longitudinal speed of the system, and/or one or more user defined inputs to the controller 26 provided via the user interface 28.

[0031] In an exemplary embodiment, at least one of the sensors 28 includes a conventional strain gauge that senses the reaction force of the tubular member 16 during the radial expansion and plastic deformation of the tubular member by the system 10. In an exemplary embodiment, increases in the sensed reaction force causes the controller 26 to increase or decrease the spring rate of one or more of the adjustable spring elements 22 thereby increasing or decreasing the stiffness of the corresponding expansion device segments 18. In this manner, the forces applied to the tubular member 16 may be increased or decreased for example, to provide increased or decreased radial expansion forces as a function of the sensed reaction forces.

[0032] In an exemplary embodiment, at least one of the sensors 28 includes a conventional pressure sensor that senses the operating pressures of fluidic materials within the system 10 and/or the tubular member 16 during the radial expansion and plastic deformation of the tubular member by the system 10. In an exemplary embodiment, the value of the sensed operating pressure causes the controller 26 to increase or decrease the spring rate of one or more of the adjustable spring elements 22 thereby increasing or decreasing the stiffness of the corresponding expansion device segments 18. In this manner, the forces applied to the tubular member 16 may be increased or decreased for example, to provide increased or decreased radial expansion forces as a function of the sensed operating pressures.

[0033] In an exemplary embodiment, the controller 26 is programmed to adaptively adjust the spring rates of one or more of the adjustable spring elements 22 and/or the damping rate of one or more of the adjustable damping elements 24 to control the frequency response of one or more of the corresponding expansion device segments to provide, for example, an underdamped, a critically damped, or an overdamped frequency response. In this manner, the system 10 can provide an adaptive expansion system having user defined operational characteristics that may vary as a function of one or more sensed operating conditions.

[0034] Referring to Fig. 3a, in an exemplary embodiment, the system 10 is used to radially expand and plastically deform the overlapping ends of tubular members, 16 and 30. In an exemplary embodiment, during the radial expansion and plastic deformation of the overlapping ends of the tubular members, 16 and 30, the reaction forces of the overlapping ends of the tubular members, 16 and 30, are sensed by one or more of the sensors 28, and, if the sensed reaction forces increase, the spring rates of one or more of the adjustable spring elements 22 of the adaptive expansion device 14 are increased to thereby increase the radial expansion forces applied to the overlapping ends of the tubular members. In this manner, the system 10 can controllably adjust the radial expansion forces applied to overlapping tubulars thereby enhancing the radial expansion process. In an alternative

embodiment, the location of the overlapped ends of the tubular members, 16 and 30, may be input into the controller 26 using the user interface 28 to control the initiation of the adjustment of the spring rates of the adjustable spring elements 22 in combination with, or in the alternative to, the sensing of the reaction forces described above.

[0035] Referring to Fig. 3b, in an exemplary embodiment, the system 10 is used to radially expand and plastically deform a tubular member 16 that includes first and second tubular members, 16a and 16b, coupled to one another by a threaded connection 32. In an exemplary embodiment, during the radial expansion and plastic deformation of the threaded connection 32, the reaction forces of the threaded connection are sensed by one or more of the sensors 28, and, the spring rates and/or the damping rate of one or more of the adjustable spring elements 22 and/or adjustable damping elements 24 of the adaptive expansion device 14 are adjusted to thereby minimize damage to the integrity of the threaded connection during the radial expansion process. For example, the spring rates one or more of the adjustable spring elements 22 may be reduced to minimize damage to the integrity of the threaded connection 32 during the radial expansion process and/or the damping rates of one or more of the adjustable damping elements 24 may be increased to minimize shock loading of the threaded connection during the radial expansion process. In an alternative embodiment, the location of the threaded connection 32 may be input into the controller 26 using the user interface 28 to control the initiation of the adjustment of the spring rates and/or damping rates of the adjustable spring elements 22 and/or damping elements 24 in combination with, or in the alternative to, the sensing of the reaction forces described above.

[0036] Referring to Fig. 3c, in an exemplary embodiment, the system 10 is used to radially expand and elastically deform a subterranean formation 34 during the radial expansion and plastic deformation of the tubular member 16. In an exemplary embodiment, during the radial expansion and plastic deformation of the tubular member 16 against the subterranean formation 34, the reaction forces of the formation 34 are sensed by one or more of the sensors 28, and the spring rates of one or more of the adjustable spring elements 22 of the adaptive expansion device 14 are increased to thereby increase the radial expansion forces applied to the formation. In this manner, the system 10 can controllably adjust the radial expansion forces applied to the formation 34 surrounding the tubular member 16 during the radial expansion and plastic deformation of the tubular member. In an alternative embodiment, the location of the formation 34 may be input into the controller 26 using the user interface 28 to control the initiation of the adjustment of the spring rates of the adjustable spring elements 22 in combination with, or in the alternative to, the sensing of the reaction forces described above.

[0037] In several alternative embodiments, the exemplary embodiments of the present disclosure are implemented using the methods and/or apparatus disclosed one or more of the following: (1) U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, which claims priority from provisional application 60/121,702, filed on 2/25/99, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (4) U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (5) U.S. patent application serial no. 10/169,434, attorney docket no. 25791.10.04, filed on 7/1/02, which claims priority from provisional application 60/183,546, filed on 2/18/00, (6) U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (7) U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (8) U.S. patent number 6,575,240, which was filed as patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, which claims priority from provisional application 60/121,907, filed on 2/26/99, (9) U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (10) U.S. patent application serial no. 09/981,916, attorney docket no. 25791.18, filed on 10/18/01 as a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (11) U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (12) U.S. patent application serial no. 10/030,593, attorney docket no. 25791.25.08, filed on 1/8/02, which claims priority from provisional application 60/146,203, filed on 7/29/99, (13) U.S. provisional patent application serial no. 60/143,039, attorney docket no. 25791.26, filed on 7/9/99, (14) U.S. patent application serial no. 10/111,982, attorney docket no. 25791.27.08, filed on 4/30/02, which claims priority from provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (15) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (16) U.S. provisional patent application

serial no. 60/438,828, attorney docket no. 25791.31, filed on 1/9/03, (17) U.S. patent number 6,564,875, which was filed as application serial no. 09/679,907, attorney docket no. 25791.34.02, on 10/5/00, which claims priority from provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (18) U.S. patent application serial no. 10/089,419, filed on 3/27/02, attorney docket no. 25791.36.03, which claims priority from provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (19) U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (20) U.S. patent application serial no. 10/303,992, filed on 11/22/02, attorney docket no. 25791.38.07, which claims priority from provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (21) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (22) U.S. provisional patent application serial no. 60/455,051, attorney docket no. 25791.40, filed on 3/14/03, (23) PCT application US02/2477, filed on 6/26/02, attorney docket no. 25791.44.02, which claims priority from U.S. provisional patent application serial no. 60/303,711, attorney docket no. 25791.44, filed on 7/6/01, (24) U.S. patent application serial no. 10/311,412, filed on 12/12/02, attorney docket no. 25791.45.07, which claims priority from provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (25) U.S. patent application serial no. 10/, filed on 12/18/02, attorney docket no. 25791.46.07, which claims priority from provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (26) U.S. patent application serial no. 10/322,947, filed on 1/22/03, attorney docket no. 25791.47.03, which claims priority from provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (27) U.S. patent application serial no. 10/406,648, filed on 3/31/03, attorney docket no. 25791.48.06, which claims priority from provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (28) PCT application US02/04353, filed on 2/14/02, attorney docket no. 25791.50.02, which claims priority from U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (29) U.S. patent application serial no. 10/465,835, filed on 6/13/03, attorney docket no. 25791.51.06, which claims priority from provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (30) U.S. patent application serial no. 10/465,831, filed on 6/13/03, attorney docket no. 25791.52.06, which claims priority from U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (31) U.S. provisional patent application serial no. 60/452,303, filed on 3/5/03, attorney docket no. 25791.53, (32) U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a

divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (33) U.S. patent number 6,561,227, which was filed as patent application serial number 09/852,026 , filed on 5/9/01, attorney docket no. 25791.56, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (34) U.S. patent application serial number 09/852,027, filed on 5/9/01, attorney docket no. 25791.57, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (35) PCT Application US02/25608, attorney docket no. 25791.58.02, filed on 8/13/02, which claims priority from provisional application 60/318,021, filed on 9/7/01, attorney docket no. 25791.58, (36) PCT Application US02/24399, attorney docket no. 25791.59.02, filed on 8/1/02, which claims priority from U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (37) PCT Application US02/29856, attorney docket no. 25791.60.02, filed on 9/19/02, which claims priority from U.S. provisional patent application serial no. 60/326,886, attorney docket no. 25791.60, filed on 10/3/2001, (38) PCT Application US02/20256, attorney docket no. 25791.61.02, filed on 6/26/02, which claims priority from U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (39) U.S. patent application serial no. 09/962,469, filed on 9/25/01, attorney docket no. 25791.62, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (40) U.S. patent application serial no. 09/962,470, filed on 9/25/01, attorney docket no. 25791.63, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (41) U.S. patent application serial no. 09/962,471, filed on 9/25/01, attorney docket no. 25791.64, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (42) U.S. patent application serial no. 09/962,467, filed on 9/25/01, attorney docket no. 25791.65, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (43) U.S. patent application serial no. 09/962,468, filed on 9/25/01, attorney docket no. 25791.66, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application

60/124,042, filed on 3/11/99, (44) PCT application US 02/25727, filed on 8/14/02, attorney docket no. 25791.67.03, which claims priority from U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, and U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (45) PCT application US 02/39425, filed on 12/10/02, attorney docket no. 25791.68.02, which claims priority from U.S. provisional patent application serial no. 60/343,674 , attorney docket no. 25791.68, filed on 12/27/2001, (46) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (47) U.S. utility patent application serial no. 10/516,467, attorney docket no. 25791.70, filed on 12/10/01, which is a continuation application of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (48) PCT application US 03/00609, filed on 1/9/03, attorney docket no. 25791.71.02, which claims priority from U.S. provisional patent application serial no. 60/357,372 , attorney docket no. 25791.71, filed on 2/15/02, (49) U.S. patent application serial no. 10/074,703, attorney docket no. 25791.74, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (50) U.S. patent application serial no. 10/074,244, attorney docket no. 25791.75, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (51) U.S. patent application serial no. 10/076,660, attorney docket no. 25791.76, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (52) U.S. patent application serial no. 10/076,661, attorney docket no. 25791.77, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (53) U.S. patent application serial no. 10/076,659, attorney docket no. 25791.78, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no.

25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (54) U.S. patent application serial no. 10/078,928, attorney docket no. 25791.79, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (55) U.S. patent application serial no. 10/078,922, attorney docket no. 25791.80, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (56) U.S. patent application serial no. 10/078,921, attorney docket no. 25791.81, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (57) U.S. patent application serial no. 10/261,928, attorney docket no. 25791.82, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (58) U.S. patent application serial no. 10/079,276 , attorney docket no. 25791.83, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (59) U.S. patent application serial no. 10/262,009, attorney docket no. 25791.84, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (60) U.S. patent application serial no. 10/092,481, attorney docket no. 25791.85, filed on 3/7/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (61) U.S. patent application serial no. 10/261,926, attorney docket no. 25791.86, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (62) PCT application US 02/36157, filed on 11/12/02, attorney docket no. 25791.87.02, which claims priority from U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/01, (63) PCT application US 02/36267, filed on 11/12/02, attorney docket no. 25791.88.02, which claims priority from U.S. provisional patent application serial no. 60/339,013, attorney docket no.

25791.88, filed on 11/12/01, (64) PCT application US 03/11765, filed on 4/16/03, attorney docket no. 25791.89.02, which claims priority from U.S. provisional patent application serial no. 60/383,917, attorney docket no. 25791.89, filed on 5/29/02, (65) PCT application US 03/15020, filed on 5/12/03, attorney docket no. 25791.90.02, which claims priority from U.S. provisional patent application serial no. 60/391,703, attorney docket no. 25791.90, filed on 6/26/02, (66) PCT application US 02/39418, filed on 12/10/02, attorney docket no. 25791.92.02, which claims priority from U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/02, (67) PCT application US 03/06544, filed on 3/4/03, attorney docket no. 25791.93.02, which claims priority from U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/02, (68) U.S. patent application serial no. 10/331,718, attorney docket no. 25791.94, filed on 12/30/02, which is a divisional U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (69) PCT application US 03/04837, filed on 2/29/03, attorney docket no. 25791.95.02, which claims priority from U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/02, (70) U.S. patent application serial no. 10/261,927, attorney docket no. 25791.97, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (71) U.S. patent application serial no. 10/262,008, attorney docket no. 25791.98, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (72) U.S. patent application serial no. 10/261,925, attorney docket no. 25791.99, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (73) U.S. patent application serial no. 10/199,524, attorney docket no. 25791.100, filed on 7/19/02, which is a continuation of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (74) PCT application US 03/10144, filed on 3/28/03, attorney docket no. 25791.101.02, which claims priority from U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/02, (75) U.S. provisional patent application serial no. 60/412,542, attorney docket no. 25791.102, filed on 9/20/02, (76) PCT application US 03/14153, filed on 5/6/03, attorney docket no. 25791.104.02, which claims priority from U.S. provisional patent

application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/02, (77) PCT application US 03/19993, filed on 6/24/03, attorney docket no. 25791.106.02, which claims priority from U.S. provisional patent application serial no. 60/397,284, attorney docket no. 25791.106, filed on 7/19/02, (78) PCT application US 03/13787, filed on 5/5/03, attorney docket no. 25791.107.02, which claims priority from U.S. provisional patent application serial no. 60/387,486 , attorney docket no. 25791.107, filed on 6/10/02, (79) PCT application US 03/18530, filed on 6/11/03, attorney docket no. 25791.108.02, which claims priority from U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/02, (80) PCT application US 03/20694, filed on 7/1/03, attorney docket no. 25791.110.02, which claims priority from U.S. provisional patent application serial no. 60/398,061, attorney docket no. 25791.110, filed on 7/24/02, (81) PCT application US 03/20870, filed on 7/2/03, attorney docket no. 25791.111.02, which claims priority from U.S. provisional patent application serial no. 60/399,240, attorney docket no. 25791.111, filed on 7/29/02, (82) U.S. provisional patent application serial no. 60/412,487, attorney docket no. 25791.112, filed on 9/20/02, (83) U.S. provisional patent application serial no. 60/412,488, attorney docket no. 25791.114, filed on 9/20/02, (84) U.S. patent application serial no. 10/280,356, attorney docket no. 25791.115, filed on 10/25/02, which is a continuation of U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (85) U.S. provisional patent application serial no. 60/412,177, attorney docket no. 25791.117, filed on 9/20/02, (86) U.S. provisional patent application serial no. 60/412,653, attorney docket no. 25791.118, filed on 9/20/02, (87) U.S. provisional patent application serial no. 60/405,610, attorney docket no. 25791.119, filed on 8/23/02, (88) U.S. provisional patent application serial no. 60/405,394, attorney docket no. 25791.120, filed on 8/23/02, (89) U.S. provisional patent application serial no. 60/412,544, attorney docket no. 25791.121, filed on 9/20/02, (90) PCT application US 03/24779, filed on 8/8/03, attorney docket no. 25791.125.02, which claims priority from U.S. provisional patent application serial no. 60/407,442, attorney docket no. 25791.125, filed on 8/30/02, (91) U.S. provisional patent application serial no. 60/423,363, attorney docket no. 25791.126, filed on 12/10/02, (92) U.S. provisional patent application serial no. 60/412,196, attorney docket no. 25791.127, filed on 9/20/02, (93) U.S. provisional patent application serial no. 60/412,187, attorney docket no. 25791.128, filed on 9/20/02, (94) U.S. provisional patent application serial no. 60/412,371, attorney docket no. 25791.129, filed on 9/20/02, (95) U.S. patent application serial no. 10/382,325, attorney docket no. 25791.145, filed on 3/5/03, which is a continuation of U.S. patent number 6,557,640, which was filed as patent application serial

no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (96) U.S. patent application serial no. 10/624,842, attorney docket no. 25791.151, filed on 7/22/03, which is a divisional of U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (97) U.S. provisional patent application serial no. 60/431,184, attorney docket no. 25791.157, filed on 12/5/02, (98) U.S. provisional patent application serial no. 60/448,526, attorney docket no. 25791.185, filed on 2/18/03, (99) U.S. provisional patent application serial no. 60/461,539, attorney docket no. 25791.186, filed on 4/9/03, (100) U.S. provisional patent application serial no. 60/462,750, attorney docket no. 25791.193, filed on 4/14/03, (101) U.S. provisional patent application serial no. 60/436,106, attorney docket no. 25791.200, filed on 12/23/02, (102) U.S. provisional patent application serial no. 60/442,942, attorney docket no. 25791.213, filed on 1/27/03, (103) U.S. provisional patent application serial no. 60/442,938, attorney docket no. 25791.225, filed on 1/27/03, (104) U.S. provisional patent application serial no. 60/418,687, attorney docket no. 25791.228, filed on 4/18/03, (105) U.S. provisional patent application serial no. 60/454,896, attorney docket no. 25791.236, filed on 3/14/03, (106) U.S. provisional patent application serial no. 60/450,504, attorney docket no. 25791.238, filed on 2/26/03, (107) U.S. provisional patent application serial no. 60/451,152, attorney docket no. 25791.239, filed on 3/9/03, (108) U.S. provisional patent application serial no. 60/455,124, attorney docket no. 25791.241, filed on 3/17/03, (109) U.S. provisional patent application serial no. 60/453,678, attorney docket no. 25791.253, filed on 3/11/03, (110) U.S. patent application serial no. 10/421,682, attorney docket no. 25791.256, filed on 4/23/03, which is a continuation of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (111) U.S. provisional patent application serial no. 60/457,965, attorney docket no. 25791.260, filed on 3/27/03, (112) U.S. provisional patent application serial no. 60/455,718, attorney docket no. 25791.262, filed on 3/18/03, (113) U.S. patent number 6,550,821, which was filed as patent application serial no. 09/811,734, filed on 3/19/01, (114) U.S. patent application serial no. 10/436,467, attorney docket no. 25791.268, filed on 5/12/03, which is a continuation of U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (115) U.S. provisional patent application serial no. 60/459,776, attorney docket no. 25791.270, filed on 4/2/03, (116) U.S. provisional patent application serial no. 60/461,094, attorney docket no. 25791.272, filed on 4/8/03, (117) U.S. provisional patent application serial no. 60/461,038, attorney docket no. 25791.273, filed on 4/7/03, (118) U.S. provisional patent application serial no. 60/463,586, attorney docket no.

25791.277, filed on 4/17/03, (119) U.S. provisional patent application serial no. 60/472,240, attorney docket no. 25791.286, filed on 5/20/03, (120) U.S. patent application serial no. 10/619,285, attorney docket no. 25791.292, filed on 7/14/03, which is a continuation-in-part of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (121) U.S. utility patent application serial no. 10/418,688, attorney docket no. 25791.257, which was filed on 4/18/03, as a division of U.S. utility patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (122) PCT patent application serial no. PCT/US04/_____, attorney docket no. 25791.238.02, filed on 2/26/2004, (123) PCT patent application serial number PCT/US04/_____, attorney docket number 25791.40.02, filed on 3/15/04_____, (124) PCT patent application serial number PCT/US04/_____, attorney docket number 25791.236.02, filed on 3/15/04, and (125) PCT patent application serial number PCT/US04/_____, attorney docket number 25791.253.02, filed on 3/11/2004, (125) conventional rotary expansion tools such as, for example, as described in U.S. 6,457,532 and/or WO 02/081863 A1, or any one of the commercially available rotary expansion tools available from Weatherford International, Inc., and/or (126) conventional hydro-forming methods and tools, the disclosures of which are incorporated herein by reference.

[0038] More generally, the operational characteristics of the adaptive expansion device 14 may be determined as a function of empirical data regarding the tubular member 16 determined during a radial expansion testing procedure. For example, if a certain spring rate and/or damping rate, or range and/or variation in spring rate and/or damping rate, for one or more of the adjustable spring elements 22 and/or one or more of the adjustable damping elements 24 provide enhanced operational performance of the tubular member 16, before, during or after, a radial expansion and plastic deformation of the tubular member, then the preferred spring rate and/or damping rate, or the range and/or variation in the spring rate and/or damping rate, for one or more of the adjustable spring elements 22 and/or one or more of the adjustable damping elements 24 may be programmed into the controller 26 to thereby provide enhanced radial expansion and plastic deformation of the tubular member using the adaptive expansion device 14.

[0039] An apparatus for radially expanding and plastically deforming a tubular member has been described that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member that includes a support structure coupled to the support member; one or more expansion

device segments for engaging the tubular member to thereby radially expand and plastically deform the tubular member; one or more adjustable spring elements coupled between the support structure and one or more of the expansion device segments; one or more adjustable damping elements coupled between the support structure and one or more of the expansion device segments; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member by the adaptive expansion device; a controller operably coupled to the adjustable spring elements, the adjustable damping elements, and the sensors; and a user interface operably coupled to the controller for receiving user inputs; wherein the controller is programmed to controllably adjust a spring rate of one or more of the adjustable spring elements, and a damping rate of one or more of the damping elements as a function of the operating conditions sensed by the sensors and the user inputs.

[0040] A method of adaptively radially expanding a tubular member within a wellbore has been described that includes inserting an adaptive expansion device into the tubular member; radially expanding and plastically deforming the tubular member using the adaptive expansion device; sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and as a function of the sensed operating conditions, controllably adjusting a spring rate and a damping rate of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[0041] A system for adaptively radially expanding a tubular member within a wellbore has been described that includes means for inserting an adaptive expansion device into the tubular member; means for radially expanding and plastically deforming the tubular member using the adaptive expansion device; means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and means for, as a function of the sensed operating conditions, controllably adjusting a spring rate and a damping rate of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[0042] An apparatus for radially expanding and plastically deforming a tubular member has been described that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member that includes a support structure coupled to the support member; one or more expansion device segments for engaging the tubular member to thereby radially expand and plastically deform the tubular member; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member by the adaptive expansion device; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust a frequency characteristic of one or more of the expansion device segments as a function of the

operating conditions sensed by the sensors.

[0043] A method of adaptively radially expanding a tubular member within a wellbore has been described that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the tubular member; radially expanding and plastically deforming the tubular member using the adaptive expansion device; sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and as a function of the sensed operating conditions, controllably adjusting a frequency response characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member.

[0044] A system for adaptively radially expanding a tubular member within a wellbore has been described that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the tubular member; means for radially expanding and plastically deforming the tubular member using the adaptive expansion device; means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and means for, as a function of the sensed operating conditions, controllably adjusting a frequency response characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member.

[0045] An apparatus for radially expanding and plastically deforming overlapping ends of first and second tubular members has been described that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the overlapping ends of the tubular members that includes a support structure coupled to the support member; one or more expansion device segments for engaging the overlapping ends of the tubular members to thereby radially expand and plastically deform the overlapping ends of the tubular member; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the overlapping ends of the tubular member by the adaptive expansion device; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the overlapping ends of the tubular members by one or more of the sensors.

[0046] A method of adaptively radially expanding overlapping ends of tubular members within a wellbore has been described that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the overlapping ends of the tubular

members; radially expanding and plastically deforming the overlapping ends of the tubular members using the adaptive expansion device; sensing the overlapping ends of the tubular members during the radial expansion and plastic deformation of the overlapping ends of the tubular members; and as a function of the sensing of the overlapping ends of the tubular members, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the overlapping ends of the tubular members.

[0047] A system for adaptively radially expanding overlapping ends of tubular members within a wellbore has been described that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the overlapping ends of the tubular members; means for radially expanding and plastically deforming the overlapping ends of the tubular members using the adaptive expansion device; means for sensing the overlapping ends of the tubular members during the radial expansion and plastic deformation of the overlapping ends of the tubular members; and means for, as a function of the sensing of the overlapping ends of the tubular members, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the overlapping ends of the tubular members.

[0048] An apparatus for radially expanding and plastically deforming first and second tubular members coupled to one another by a threaded connection has been described that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the threaded connection that includes a support structure coupled to the support member; one or more expansion device segments for engaging the threaded connection to thereby radially expand and plastically deform the threaded connection; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the threaded connection by the adaptive expansion device; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the threaded connection by one or more of the sensors.

[0049] A method of adaptively radially expanding tubular members coupled to one another by a threaded connection within a wellbore has been described that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular members proximate the threaded connection; radially expanding and plastically deforming the threaded connection using the adaptive expansion device; sensing the threaded connection during the radial expansion and plastic deformation of the threaded connection; and as a function of the

sensing of the threaded connection, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the threaded connection.

[0050] A system for adaptively radially expanding tubular members coupled to one another by a threaded connection within a wellbore has been described that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular members proximate the threaded connection; means for radially expanding and plastically deforming the threaded connection using the adaptive expansion device; means for sensing the threaded connection during the radial expansion and plastic deformation of the threaded connection; and means for, as a function of the sensing of the threaded connection, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the threaded connection.

[0051] An apparatus for radially expanding and plastically deforming a tubular member within a wellbore that traverses a subterranean formation has been described that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation that includes a support structure coupled to the support member; one or more expansion device segments for engaging the threaded connection to thereby radially expand and plastically deform the tubular member and elastically deform the subterranean formation; and one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and a controller operably coupled to the expansion device segments and the sensors; wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the subterranean formation by one or more of the sensors.

[0052] A method of adaptively radially expanding a tubular member within a wellbore that traverses a subterranean formation has been described that includes inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation within the wellbore; radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation using the adaptive expansion device; sensing the subterranean formation during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and as a function of the sensing of the subterranean formation, controllably adjusting an operational characteristic of one or more of the expansion device segments

during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation.

[0053] A system for adaptively radially expanding a tubular member within a wellbore that traverses a subterranean formation has been described that includes means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation within the wellbore; means for radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation using the adaptive expansion device; means for sensing the subterranean formation during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and means for, as a function of the sensing of the subterranean formation, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation.

[0054] An apparatus for radially expanding and plastically deforming a tubular member has been described that includes a support member; and an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member that includes a support structure coupled to the support member; and one or more expansion device segments coupled to the support structure for engaging the tubular member to thereby radially expand and plastically deform the tubular member; one or more sensors for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and a controller operably coupled to the expansion device segments and the sensors; and wherein the controller is programmed to controllably adjust one or more of the operational characteristics of one or more the expansion device segments as a function of the operating conditions sensed by the sensors.

[0055] A method of adaptively radially expanding a tubular member within a wellbore has been described that includes inserting an adaptive expansion device into the tubular member; radially expanding and plastically deforming the tubular member using the adaptive expansion device; sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and as a function of the sensed operating conditions, controllably adjusting one or more of the operating characteristics of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[0056] A system for adaptively radially expanding a tubular member within a wellbore has been described that includes means for inserting an adaptive expansion device into the tubular member; means for radially expanding and plastically deforming the tubular member using the adaptive expansion device; means for sensing one or more operating conditions

during the radial expansion and plastic deformation of the tubular member; and means for, as a function of the sensed operating conditions, controllably adjusting one or more of the operating characteristics of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

[0057] In several exemplary embodiments, one or more of the expansion device segments includes one or more expansion surfaces; and an actuator coupled to the expansion surfaces. In an exemplary embodiment, the actuator includes one or more degrees of freedom. In an exemplary embodiment, the actuator includes a plurality of degrees of freedom. In an exemplary embodiment, the actuator includes one or more rotary actuators. In an exemplary embodiment, one or more of the expansion device segments include one or more hydro-forming devices.

[0058] In several exemplary embodiments, radially expanding and plastically deforming the tubular member using the adaptive expansion device includes displacing the adaptive expansion device relative to the tubular member in the longitudinal direction. In several exemplary embodiments, radially expanding and plastically deforming the tubular member using the adaptive expansion device includes rotating the adaptive expansion device relative to the tubular member. In an exemplary embodiment, radially expanding and plastically deforming the tubular member using the adaptive expansion device includes applying a pressurized fluid to the interior surface of the tubular member. In several exemplary embodiments, the means for radially expanding and plastically deforming the tubular member using the adaptive expansion device includes means for displacing the adaptive expansion device. In several exemplary embodiments, the means for displacing the adaptive expansion device includes one or more degrees of freedom. In several exemplary embodiments, the means for displacing the adaptive expansion device includes a plurality of degrees of freedom. In several exemplary embodiments, the means for radially expanding and plastically deforming the tubular member using the adaptive expansion device includes means for radially expanding and plastically deforming the tubular member using a hydro-forming device.

[0059] It is understood that variations may be made in the foregoing without departing from the scope of the invention. For example, the teachings of the present illustrative embodiments may be used to provide a wellbore casing, a pipeline, or a structural support. Furthermore, one or more of the tubular members, 16 and 30, may be slotted, perforated, or otherwise include one or more radial passages. In addition, the adaptive expansion device 14 may be displaced in the longitudinal direction and/or rotated relative to the tubular member 16 during the radial expansion and plastic deformation of the tubular member.

[0060] Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing

disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

Claims

What is claimed is:

1. An apparatus for radially expanding and plastically deforming a tubular member, comprising:

a support member; and

an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member, comprising:

a support structure coupled to the support member;

one or more expansion device segments for engaging the tubular member to thereby radially expand and plastically deform the tubular member;

one or more adjustable spring elements coupled between the support structure and one or more of the expansion device segments;

one or more adjustable damping elements coupled between the support structure and one or more of the expansion device segments; and

one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member by the adaptive expansion device;

a controller operably coupled to the adjustable spring elements, the adjustable damping elements, and the sensors; and

a user interface operably coupled to the controller for receiving user inputs;

wherein the controller is programmed to controllably adjust a spring rate of one or more of the adjustable spring elements, and a damping rate of one or more of the damping elements as a function of the operating conditions sensed by the sensors and the user inputs.

2. A method of adaptively radially expanding a tubular member within a wellbore, comprising:

inserting an adaptive expansion device into the tubular member;

radially expanding and plastically deforming the tubular member using the adaptive expansion device;

sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

as a function of the sensed operating conditions, controllably adjusting a spring rate and a damping rate of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

3. A system for adaptively radially expanding a tubular member within a wellbore, comprising:

means for inserting an adaptive expansion device into the tubular member;

means for radially expanding and plastically deforming the tubular member using the adaptive expansion device;

means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

means for, as a function of the sensed operating conditions, controllably adjusting a spring rate and a damping rate of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

4. An apparatus for radially expanding and plastically deforming a tubular member, comprising:

a support member; and

an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member, comprising:

a support structure coupled to the support member;

one or more expansion device segments for engaging the tubular member to thereby radially expand and plastically deform the tubular member; and

one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member by the adaptive expansion device; and

a controller operably coupled to the expansion device segments and the sensors;

wherein the controller is programmed to controllably adjust a frequency characteristic of one or more of the expansion device segments as a function of the operating conditions sensed by the sensors.

5. A method of adaptively radially expanding a tubular member within a wellbore, comprising:

inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the tubular member;

radially expanding and plastically deforming the tubular member using the adaptive expansion device;

sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

as a function of the sensed operating conditions, controllably adjusting a frequency response characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member.

6. A system for adaptively radially expanding a tubular member within a wellbore, comprising:

means for inserting an adaptive expansion device comprising one or more expansion

device segments for engaging and radially expanding and plastically deforming the tubular member into the tubular member;

means for radially expanding and plastically deforming the tubular member using the adaptive expansion device;

means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

means for, as a function of the sensed operating conditions, controllably adjusting a frequency response characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member.

7. An apparatus for radially expanding and plastically deforming overlapping ends of first and second tubular members, comprising:

a support member; and

an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the overlapping ends of the tubular members, comprising:

a support structure coupled to the support member;

one or more expansion device segments for engaging the overlapping ends of the tubular members to thereby radially expand and plastically deform the overlapping ends of the tubular member; and

one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the overlapping ends of the tubular member by the adaptive expansion device; and

a controller operably coupled to the expansion device segments and the sensors;

wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the overlapping ends of the tubular members by one or more of the sensors.

8. A method of adaptively radially expanding overlapping ends of tubular members within a wellbore, comprising:

inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the overlapping ends of the tubular members;

radially expanding and plastically deforming the overlapping ends of the tubular members using the adaptive expansion device;

sensing the overlapping ends of the tubular members during the radial expansion and plastic deformation of the overlapping ends of the tubular members; and

as a function of the sensing of the overlapping ends of the tubular members, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the overlapping ends of the tubular members.

9. A system for adaptively radially expanding overlapping ends of tubular members within a wellbore, comprising:

means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member into the overlapping ends of the tubular members;

means for radially expanding and plastically deforming the overlapping ends of the tubular members using the adaptive expansion device;

means for sensing the overlapping ends of the tubular members during the radial expansion and plastic deformation of the overlapping ends of the tubular members; and

means for, as a function of the sensing of the overlapping ends of the tubular members, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the overlapping ends of the tubular members.

10. An apparatus for radially expanding and plastically deforming first and second tubular members coupled to one another by a threaded connection, comprising:

a support member; and

an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the threaded connection, comprising:

a support structure coupled to the support member;

one or more expansion device segments for engaging the threaded connection to thereby radially expand and plastically deform the threaded connection; and

one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the threaded connection by the adaptive expansion device; and

a controller operably coupled to the expansion device segments and the sensors;

wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the threaded connection by one or more of the sensors.

11. A method of adaptively radially expanding tubular members coupled to one another by a threaded connection within a wellbore, comprising:

inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular members proximate the threaded connection;

radially expanding and plastically deforming the threaded connection using the adaptive expansion device;

sensing the threaded connection during the radial expansion and plastic deformation of the threaded connection; and

as a function of the sensing of the threaded connection, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the threaded connection.

12. A system for adaptively radially expanding tubular members coupled to one another by a threaded connection within a wellbore, comprising:

means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular members proximate the threaded connection;

means for radially expanding and plastically deforming the threaded connection using the adaptive expansion device;

means for sensing the threaded connection during the radial expansion and plastic deformation of the threaded connection; and

means for, as a function of the sensing of the threaded connection, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the threaded connection.

13. An apparatus for radially expanding and plastically deforming a tubular member within a wellbore that traverses a subterranean formation, comprising:

a support member; and

an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation, comprising:

a support structure coupled to the support member;

one or more expansion device segments for engaging the threaded connection to thereby radially expand and plastically deform the tubular member and elastically deform the subterranean formation; and

one or more sensors for sensing operating conditions during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and

a controller operably coupled to the expansion device segments and the sensors;

wherein the controller is programmed to controllably adjust one or more operational characteristics of one or more of the expansion device segments as a function of a sensing of the subterranean formation by one or more of the sensors.

14. A method of adaptively radially expanding a tubular member within a wellbore that traverses a subterranean formation, comprising:

inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation within the wellbore;

radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation using the adaptive expansion device;

sensing the subterranean formation during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and

as a function of the sensing of the subterranean formation, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation.

15. A system for adaptively radially expanding a tubular member within a wellbore that traverses a subterranean formation, comprising:

means for inserting an adaptive expansion device comprising one or more expansion device segments for engaging and radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation within the wellbore;

means for radially expanding and plastically deforming the tubular member and elastically deforming the subterranean formation using the adaptive expansion device;

means for sensing the subterranean formation during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation; and

means for, as a function of the sensing of the subterranean formation, controllably adjusting an operational characteristic of one or more of the expansion device segments during the radial expansion and plastic deformation of the tubular member and the elastic deformation of the subterranean formation.

16. An apparatus for radially expanding and plastically deforming a tubular

member, comprising:

a support member; and

an adaptive expansion device coupled to the support member for radially expanding and plastically deforming the tubular member, comprising:

a support structure coupled to the support member; and

one or more expansion device segments coupled to the support structure for engaging the tubular member to thereby radially expand and plastically deform the tubular member;

one or more sensors for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

a controller operably coupled to the expansion device segments and the sensors; and

wherein the controller is programmed to controllably adjust one or more of the operational characteristics of one or more the expansion device segments as a function of the operating conditions sensed by the sensors.

17. A method of adaptively radially expanding a tubular member within a wellbore, comprising:

inserting an adaptive expansion device into the tubular member;

radially expanding and plastically deforming the tubular member using the adaptive expansion device;

sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

as a function of the sensed operating conditions, controllably adjusting one or more of the operating characteristics of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

18. A system for adaptively radially expanding a tubular member within a wellbore, comprising:

means for inserting an adaptive expansion device into the tubular member;

means for radially expanding and plastically deforming the tubular member using the adaptive expansion device;

means for sensing one or more operating conditions during the radial expansion and plastic deformation of the tubular member; and

means for, as a function of the sensed operating conditions, controllably adjusting one or more of the operating characteristics of the adaptive expansion device during the radial expansion and plastic deformation of the tubular member.

19. The apparatus of claims 1, 4, 7, 10, 13, or 16, wherein one or more of the expansion device segments comprise:

one or more expansion surfaces; and

an actuator coupled to the expansion surfaces.

20. The apparatus of claim 19, wherein the actuator comprises one or more degrees of freedom.

21. The apparatus of claim 20, wherein the actuator comprises a plurality of degrees of freedom.

22. The apparatus of claim 19, wherein the actuator comprises one or more rotary actuators.

23. The apparatus of claims 1, 4, 7, 10, 13, or 16, wherein one or more of the expansion device segments comprise:

one or more hydro-forming devices.

24. The method of claims 2, 5, 8, 11, 14, or 17, wherein radially expanding and plastically deforming the tubular member using the adaptive expansion device comprises:

displacing the adaptive expansion device relative to the tubular member in the longitudinal direction.

25. The method of claims 2, 5, 8, 11, 14, or 17, wherein radially expanding and plastically deforming the tubular member using the adaptive expansion device comprises:

rotating the adaptive expansion device relative to the tubular member.

26. The method of claims 2, 5, 8, 11, 14, or 17, wherein radially expanding and plastically deforming the tubular member using the adaptive expansion device comprises:

applying a pressurized fluid to the interior surface of the tubular member.

27. The system of claims 3, 6, 9, 12, 15, or 18, wherein the means for radially expanding and plastically deforming the tubular member using the adaptive expansion device comprises:

means for displacing the adaptive expansion device.

28. The system of claim 27, wherein the means for displacing the adaptive expansion device comprises one or more degrees of freedom.

29. The system of claim 27, wherein the means for displacing the adaptive expansion device comprises a plurality of degrees of freedom.

30. The system of claims 3, 6, 9, 12, 15, or 18, wherein the means for radially expanding and plastically deforming the tubular member using the adaptive expansion device comprises:

means for radially expanding and plastically deforming the tubular member using a hydro-forming device.

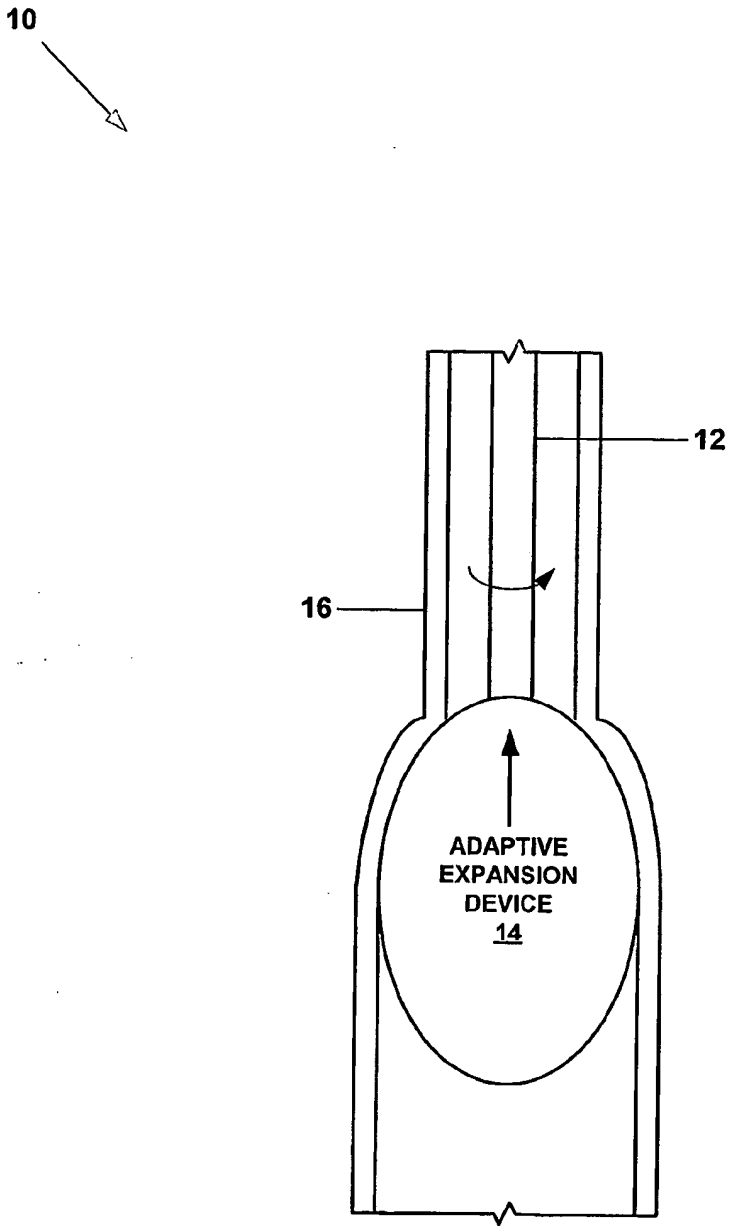


Fig. 1a

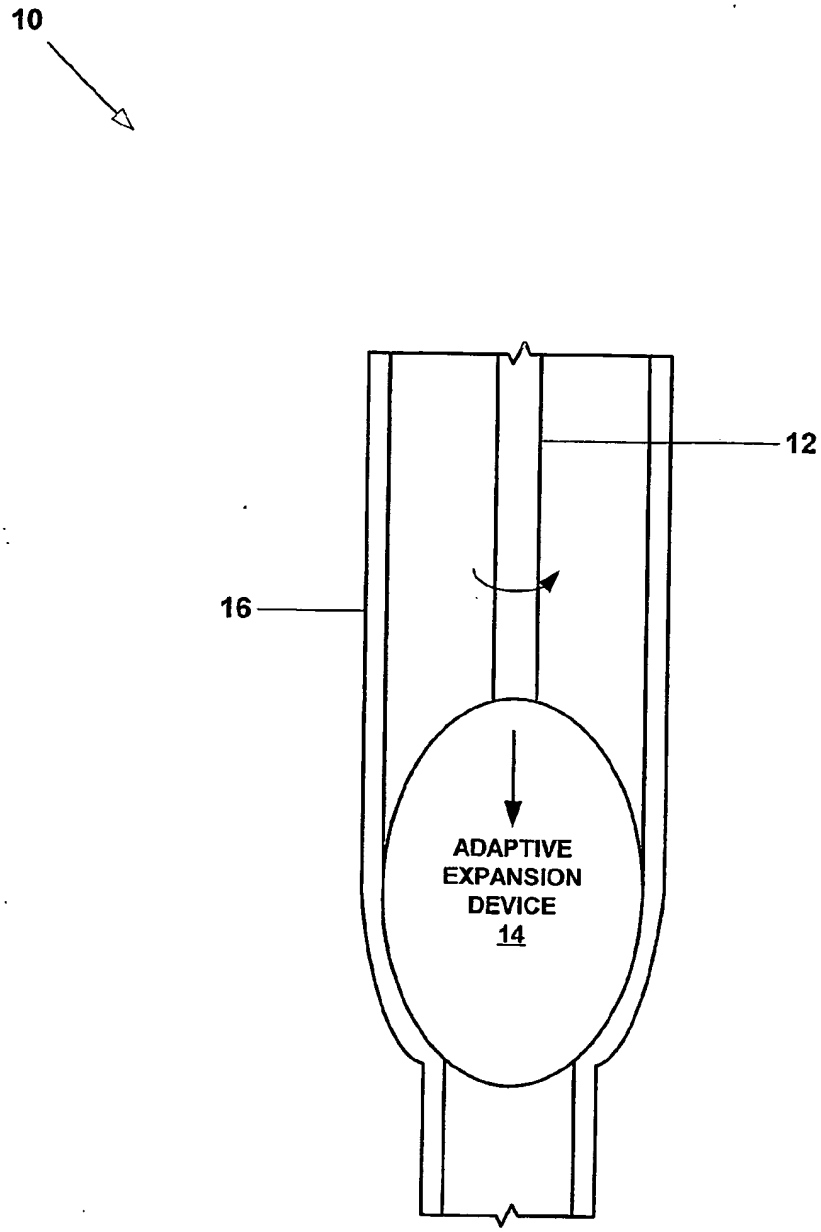
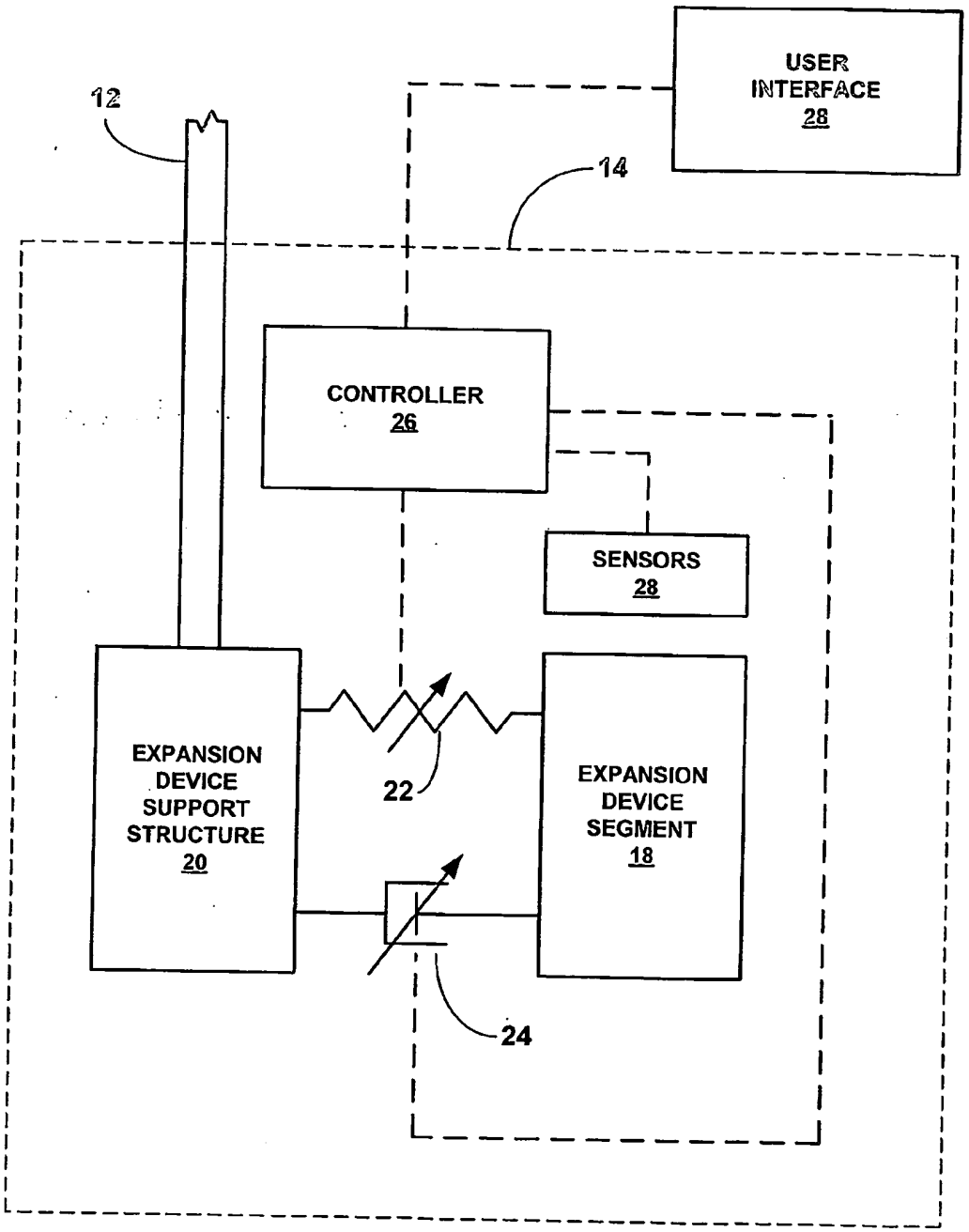


Fig. 1b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CONTROLLER 26
SENSORS 28
EXPANSION DEVICE SUPPORT STRUCTURE 20
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EXPANSION DEVICE SEGMENT 18
24

Fig. 2

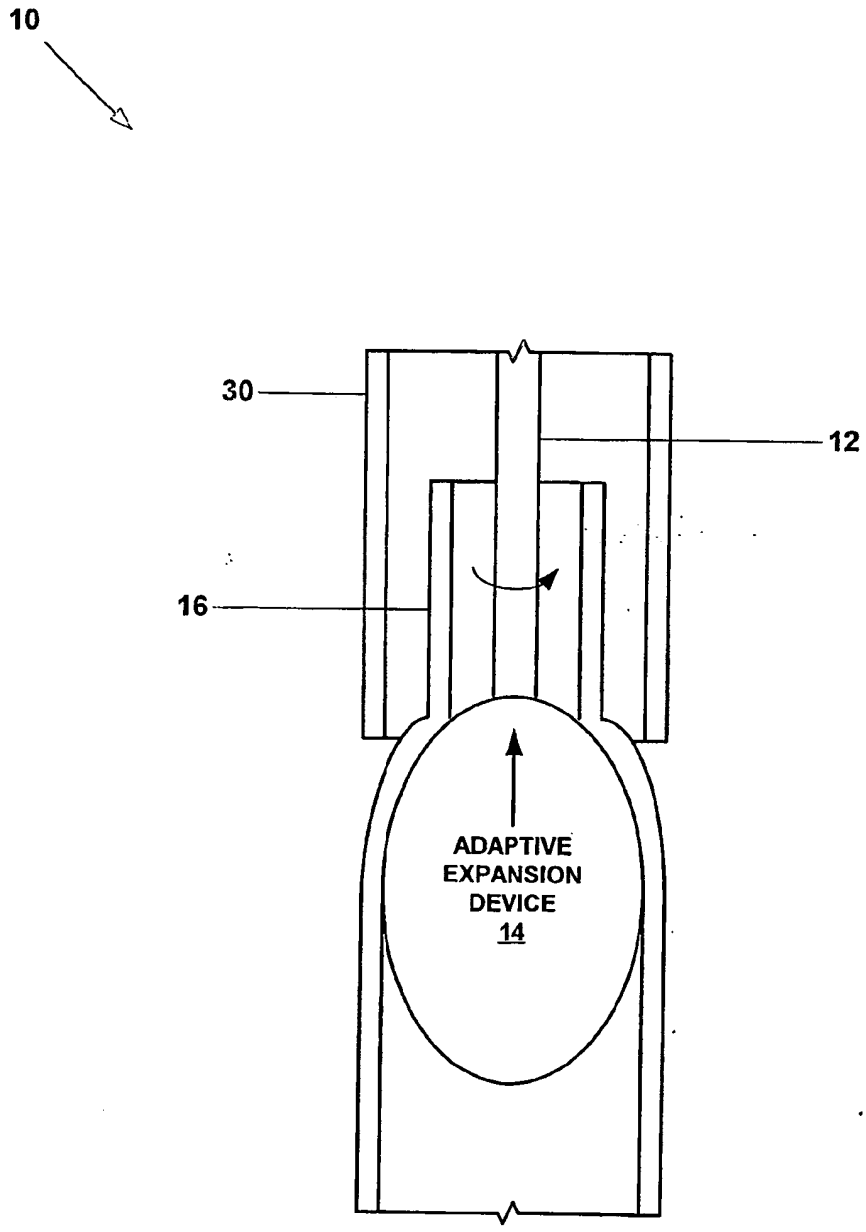

Fig. 3a

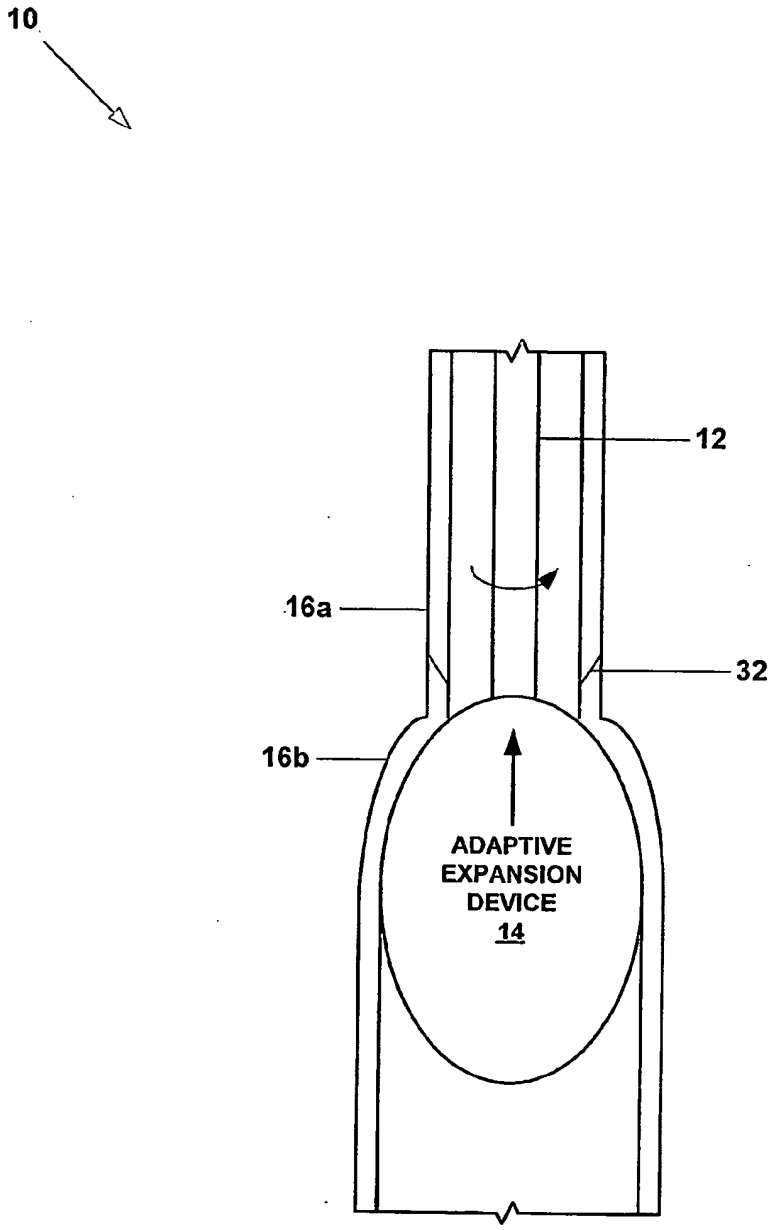

Fig. 3b

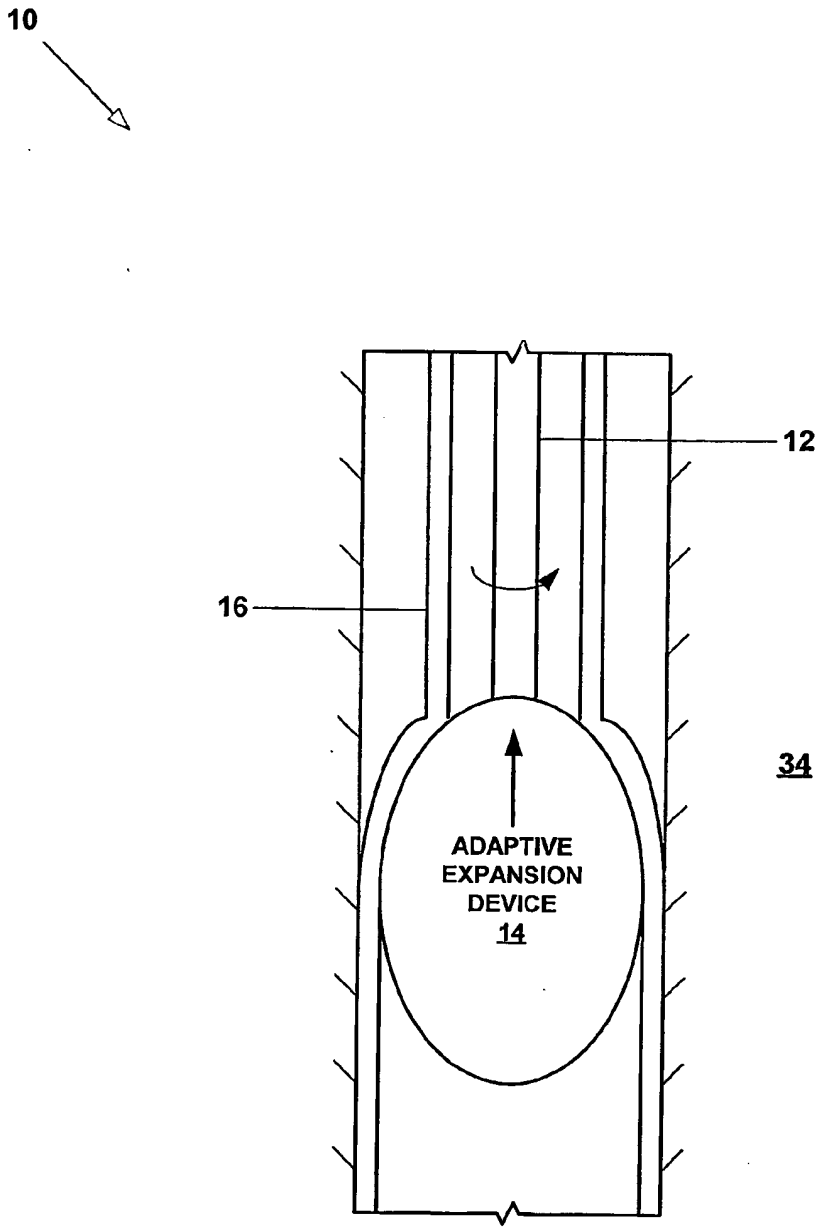

Fig. 3c

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